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Scheduling Marine Corps entry-level MOS schools

Detar, Paul J.

Monterey, California. Naval Postgraduate School

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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

SCHEDULING MARINE CORPS ENTRY-LEVEL MOS SCHOOLS

by

Paul J. Detar

September 2004

Thesis Advisor:	Robert F. Dell
Second Reader:	Roberto Szechtman

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Each year the United States Marine Corps suffers excessive loss of man years from Marines awaiting entry-level schools. During fiscal year 2001 (the most recent complete time-awaiting-training data), Marines exceeded 2,800 man years of time awaiting training. Non-infantry personnel comprise 80% of the more than 30,000 recruits shipped to Marine Corps Recruit Depots each year, but they constitute almost 95% of the 2,800 man-year loss. Marine Corps manpower planners consider the current level of loss unacceptable and believe significant improvement can be gained by optimally scheduling courses at Military Occupational Specialty (MOS) schools. This thesis uses an integer linear program, Entry-Level Course Scheduler (ELCS), to optimize a course schedule that includes recommended seat assignments by MOS and gender. ELCS seeks to minimize the time awaiting training while successfully meeting yearly classification requirements. ELCS results using fiscal year 2003 data indicate time awaiting training can be reduced to only 1,700 man years (a 1,100 man-year improvement, when compared with fiscal year 2001 data).

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SCHEDULING MARINE CORPS ENTRY-LEVEL MOS SCHOOLS

Paul J. Detar
Captain, United States Marine Corps
B.S., United States Naval Academy, 1998

Submitted in partial fulfillment of the
requirements for the degree of

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September 2004

Author: Paul J. Detar

Approved by: Robert F. Dell
Thesis Advisor

Roberto Szechtman
Second Reader

James Eagle
Chairman, Department of Operations Research

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ABSTRACT

Each year the United States Marine Corps suffers excessive loss of man years from Marines awaiting entry-level schools. During fiscal year 2001 (the most recent complete time-awaiting-training data), Marines exceeded 2,800 man years of time awaiting training. Non-infantry personnel comprise 80% of the more than 30,000 recruits shipped to Marine Corps Recruit Depots each year, but they constitute almost 95% of the 2,800 man-year loss. Marine Corps manpower planners consider the current level of loss unacceptable and believe significant improvement can be gained by optimally scheduling courses at Military Occupational Specialty (MOS) schools. This thesis uses an integer linear program, Entry-Level Course Scheduler (ELCS), to optimize a course schedule that includes recommended seat assignments by MOS and gender. ELCS seeks to minimize the time awaiting training while successfully meeting yearly classification requirements. ELCS results using fiscal year 2003 data indicate time awaiting training can be reduced to only 1,700 man years (a 1,100 man-year improvement, when compared with fiscal year 2001 data).

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LIST OF ACRONYMS

ELCS	Entry-Level Course Scheduler
GAMS	General Algebraic Modeling System
ILP	Integer Linear Program
M&RA	Deputy Commandant of the Marine Corps for Manpower and Reserve Affairs
MCRC	Marine Corps Recruiting Command
MCT	Marine Combat Training
MOS	Military Occupational Specialty
TAT	Time-Awaiting-Training
TECOM	Marine Corps Training and Education Command

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EXECUTIVE SUMMARY

Each year the United States Marine Corps suffers excessive loss of man years from Marines awaiting recruit-level schools. During fiscal year 2001 (the most recent complete time-awaiting-training data), 2,800 man years were lost to time awaiting training of new Marine recruits before completion of MOS training and reporting to their first unit. Planners at the office of the Deputy Commandant of the Marine Corps for Manpower and Reserve Affairs (M&RA) consider the current level of loss unacceptable and believe significant improvement can be gained by optimally scheduling Military Occupational Specialty (MOS) schools.

Non-infantry personnel comprise 80% of the more than 30,000 recruits shipped to Marine Corps Recruit Depots each year, but they constitute over 2,500 of the 2,800 man-year loss. An estimated 1,200 man years of the non-infantry loss occurs before Marine Combat Training (MCT) with the remaining 1,300 occurring between MCT and MOS attainment. This thesis focuses on reducing the post-MCT time-awaiting-training loss for non-infantry personnel.

Reducing time awaiting training requires close coordination between three major Marine Corps organizations: M&RA, Training and Education Command (TECOM), and Marine Corps Recruiting Command (MCRC). M&RA calculates yearly personnel requirements and coordinates with TECOM and MCRC to ensure the proper numbers are attained. Approximately two years before execution, M&RA submits a yearly training requirement to TECOM by MOS. TECOM passes this requirement along to its MOS schools by trimester. M&RA also develops a Program Plan one year before execution that dictates monthly recruitment by gender and enlistment option program.

The Marine Corps sends its 175 non-infantry MOSs to 95 different courses (30 operated at Marine installations) immediately following Marine Combat Training. Currently these schools create their own yearly schedule using a trimester training requirement from TECOM. Other planning documents, such as the Program Plan and each Recruiting Region's weekly shipping percentage goals, are not considered nor do

schools coordinate their schedules. We show an opportunity exists to reduce time awaiting training by coordinating MOS school schedules with the Program Plan. The most efficient coordination would require creation of a centrally planned master schedule after publishing the Program Plan.

This thesis uses an integer linear program, Entry-Level Course Scheduler (ELCS), to suggest an optimized course schedule including recommended seat assignments by MOS and gender. ELCS seeks to minimize the time awaiting training while successfully meeting yearly classification requirements. The program uses all yearly planning documents from M&RA, MCRC, and TECOM to create a centrally coordinated master schedule for all initial MOS courses.

Using fiscal year 2003 data, our results indicate a reduction in the post-MCT time awaiting training loss from 1,300 to 165 man years. This would reduce the 2,800 total man-year losses to 1,665, an improvement of 40% over fiscal year 2001 data. Results also indicate increasing current course frequencies and size has no significant impact on reducing time awaiting training, when using an optimal master schedule. In fact, under ideal conditions, ELCS has no use for 258 of the 2,459 allowable course offerings.

We recommend the Marine Corps adopt the findings of this thesis and conduct all future MOS school scheduling using centralized planning, decentralized execution with all available planning documents. ELCS can help the Marine Corps realize the full savings available.

I. INTRODUCTION

A. PURPOSE

This thesis optimally schedules entry-level Military Occupational Specialty (MOS) schools for non-infantry Marines. Marines attending these schools comprise 80% of all new recruits [Bicknell 2003]. Prior to their MOS school, new recruits attend Recruit Training and Marine Combat Training (MCT). Recruiting strategy, attrition, and training sequence make course scheduling difficult for planners.

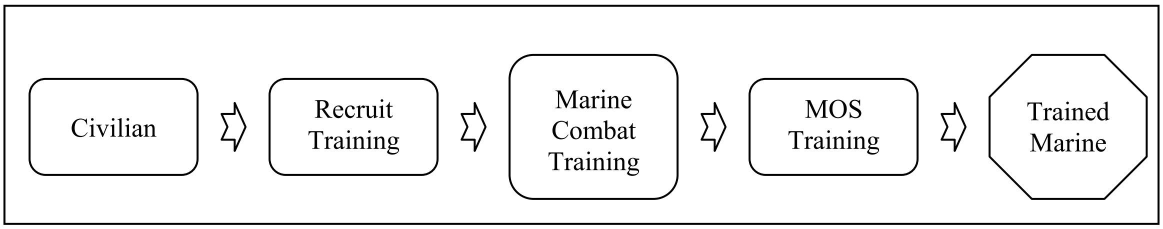

Figure 1. Training Sequence for Enlisted Non-infantry Marines.
Recruits complete Recruit Training (i.e., Boot camp), Marine Combat Training, and MOS training before arriving at their designated unit as a fully-trained Marine.

Each year the United States Marine Corps suffers excessive loss of man years from Marines awaiting MOS schools. During fiscal year 2001, Marines exceeded 2,800 man years of time awaiting training (TAT) [Bicknell 2003]. Non-infantry personnel comprise 80% of the more than 30,000 recruits shipped to Marine Corps Recruit Depots each year, but they constitute almost 95% of the 2,800 man-year loss. Those Marines assigned an infantry MOS do not attend MCT and are not considered in this thesis.

This thesis suggests course schedules and MOS assignment strategies that can significantly reduce TAT. We accomplish this by discovering the optimal yearly training schedule for the first MOS course attended by non-infantry Marines. The integer linear program (ILP), Entry-Level Course Scheduler (ELCS), produces a yearly course schedule under existing maximum course size and frequency constraints. By altering current training and recruiting capabilities, ELCS also offers analytical comparison of cost versus benefit.

This thesis builds on a previous thesis by Whaley [2001]. Many concepts we present here are similar to those presented by Whaley, and we have chosen whenever possible to adopt his notation for consistency.

B. CURRENT SCHEDULING AND ASSIGNMENT

The transition of a civilian to a MOS trained Marine involves interaction between three different Marine Corps Commands: Manpower and Reserve Affairs (M&RA), Training and Education Command (TECOM), Recruiting Command (MCRC) (see Figure 1). The planning evolves into a final course schedule developed by each individual schoolhouse within TECOM, a Classification Plan fulfilled by M&RA, and a Program Plan executed by MCRC.

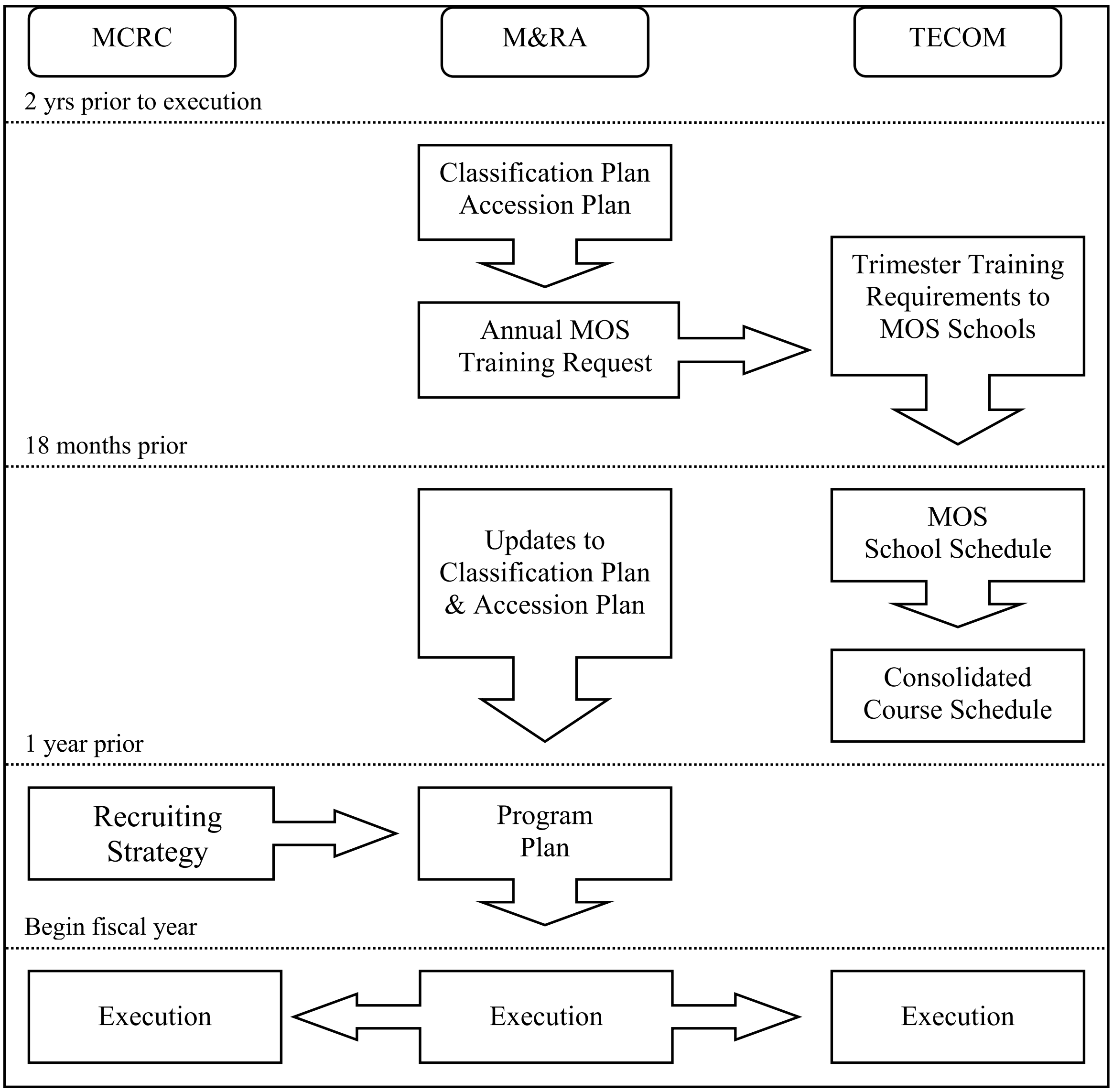

Figure 2. Output and Input Relationship of Marine Corps Commands. M&RA use the Classification Plan to make an annual training request to TECOM who pass a trimester requirement to each MOS school. Besides the trimester requirement, each MOS school publishes a yearly training schedule with no direct input or influence from the three commands.

1. Manpower and Reserve Affairs (M&RA)

M&RA builds a long-term Accession Plan to predict the number of recruits required each year to maintain the Marine Corps' end strength and a two-year-out Classification Plan that specifies the Accession Plan by MOS. M&RA uses the Classification Plan to determine their annual training request to TECOM (see Table 1). They update both plans occasionally as attrition data changes.

FY03 INITIAL CLASSIFICATION PLAN								
For Active Duty Entry-Level Marines								
MOS	STEADY STATE REQUIREMENT			POST BOOT CAMP CLASS STARTS			PLANNED SCHOOL ATTRITION	PROJECTED NUMBER OF GRADUATES
	UNADJUSTED MODEL OUTPUT	ADJUSTED FOR ACCESSIONS	BOOT/MCT GRADUATES	MALE	FEMALE	TOTAL		
0121	820	739	646	576	70	***646***	0%	646
0151	907	824	732	640	92	***732***	0%	732
0161	103	93	83	73	10	***83***	7%	77
0231	194	174	158	145	13	***158***	8%	145
0261	25	23	21	18	3	***21***	10%	19

Table 1. Example of FY2003 Classification Plan

The Classification Plan [Bicknell 2003] documents the number of Marines from each MOS who must be recruited into the Marine Corps in order to meet the projected goal of MOS trained graduates. For example, MOS 0261 requires assignment of 25 Marines to meet the Marine Corps' end-strength requirement. Their need normalizes to 23 because the total of all MOS requirements exceed allowable accessions. Of the 23, we expect 21 to graduate from Recruit Training and MCT. With an expected attrition of 10% in their MOS school, we project 19 of the 21 Marines to graduate with the 0261 MOS. The Classification Plan directly affects the Program Plan and the annual training request sent to TECOM.

M&RA also publishes a Program Plan (see Table 2) one year before the fiscal year (Oct 1 – Sept 30) that further streamlines the Classification Plan. A program within a Program Plan is a recruiting contract code that guarantees a recruit a MOS associated with his or her program. The Program Plan groups the MOS requirements from the Classification Plan into their respective programs and divides the program recruitment numbers into months based on the recruiting strategy. MCRC executes the Program Plan.

	p	TOTAL USMC	DESIRED MCRC						
		REQUIREMENT	TARGETS	OCT	NOV	DEC	JAN	FEB	MAR
AVIATION SUPPORT	AE	836	836	133	17	133	133	17	33
	AEF	94	94	9	6	6	10	5	5
AVIATION MECHANIC	AF	1734	1734	276	35	73	276	35	35
	AFF	137	137	12	9	8	14	7	7
AIRCREW	AG	417	417	38	28	25	42	21	21
	AGF	14	14	1	1	1	1	1	1

Table 2. Example of Program Plan

M&RA publishes the Program Plan [Bicknell 2003] which MCRC executes. The yearly program requirements are broken down by month. For example, program code AE requires recruitment of 836 Marines during the fiscal year of which they plan to recruit 133 in October, 17 in November, et cetera.

M&RA submits training requirements to TECOM summarizing how many Marines, by MOS, need to be trained during a fiscal year. M&RA submits this requirement approximately two years in advance based on the Classification Plan. M&RA gives no additional input on course scheduling and doesn't impact Marine Corps training until before each boot camp graduation, when it assigns every graduate a MOS. We assign Marines based on program code (or qualifications for an open contract), yearly classification requirements (from the Classification Plan), and school wait times for allowable MOSs.

2. Training and Education Command (TECOM)

TECOM receives the yearly training requirement from M&RA and forwards these to the MOS schools by four-month trimesters. Each MOS school then publishes their training calendar approximately 18 months before the fiscal year begins. TECOM consolidates all the schedules and publishes a master document.

3. Marine Corps Recruiting Command (MCRC)

MCRC partitions their recruiting year into three trimesters of four consecutive months. Starting in October, the USMC refers to these trimesters as ONDJ, FMAM, and JJAS. High school graduates compose the largest source of new recruits and become available immediately upon graduation during the JJAS trimester. The expected

percentage of the overall mission met during this period is much higher, therefore an even division of the mission across all twelve months would be inconsistent with recruiting strategy. M&RA uses the trimester recruiting percentages established by MCRC when it constructs the Program Plan.

M&RA promulgates a Program Plan to MCRC that establishes their mission one year in advance. They periodically update the numbers based on attrition and other factors. The Program Plan stipulates a required number of recruits by month, gender, and enlistment program. The recruiters are not permitted to exceed the required number of contracts per enlistment program, but they may write open contracts (a contract which does not guarantee the recruit assignment within a group of MOSs) to account for any unmet program. Open contracts can be assigned any MOS they are qualified to fill after Recruit Training graduation. Recruit stations are only given monthly goals, so there are no restrictions placed on their weekly shipment of recruits to boot camp other than boot camp availability.

C. ELCS IMPACT

Because Recruit Training and MCT are not MOS specific, the greatest loss to TAT occurs while Marines wait for their MOS school's commencement date. Although losses occur while Marines are waiting for MCT, the school typically operates at maximum frequency at class-size capacity. The baseline of loss, estimated by the author to be 1,200 man years, occurs at this stage as a result of recruiting strategy dictated by high supply months that coincide with high school graduation. The losses contributing to the baseline occur from Marines waiting for a MCT class. We see improvement at this stage infeasible without an increase to MCT's capacity or rearrangement of school sequencing. Additional losses may occur by non-optimal MOS assignment or course scheduling. We briefly discuss each of these cases.

1. Course Scheduling

Each MOS has an associated pipeline defined here, as the sequence of schools required to obtain the MOS. Sometimes multiple MOSs require the same school. ELCS accounts for students of different MOSs attending a common course concurrently. It also strives to keep students of the same MOS in groups large enough to meet follow-on

school's minimum class size requirements. We only concern ourselves with scheduling the first course in each MOS pipeline.

Currently, the MOS schools make their training schedules with little information at their disposal other than the yearly requirement and historical utilization. Some schools simply schedule to their maximum frequency and, despite obvious inefficiency, may overburden the instructors and restrict time for proper maintenance and internal training. Many of these schedules adjust during the year with courses postponing or canceling due to insufficient students or expected arrivals after a commencement date.

ELCS produces an optimal schedule with information provided by M&RA, TECOM, and MCRC. Linking vital information from all sources gives ELCS a good prediction of the system's inflow and constraints on the outflow. This allows optimal management of the limited course offerings and minimizes the time within the Marine Corps' school system.

2. MOS Assignment

Marines receive an MOS assignment approximately two weeks before Recruit Training graduation. An officer at M&RA makes the assignment using the Recruit Distribution Model, a model using both linear and nonlinear optimization, that assigns the Marine a seat at both MCT and the first course in their MOS pipeline [SRA International Inc. 2002]. The model looks at all possibilities within an acceptable timeframe (established by the operator, currently 90 days) and conducts a prioritized spread load of Marines across available schools in their program. The current system is extremely reactive because manpower planners have no input into the master course schedule nor do they have a plan outlining how many Marines of each MOS they expect to send to each school. ELCS proposes a master course schedule and gives planners visibility of the number of students attending each course in the optimal solution that derived the schedule.

3. Resource Allocation

Marine Corps planners may use ELCS to explore allocation of training resources. By altering maximum class sizes and frequency, planners can quantify TAT changes based on these policy decisions. ELCS provides support to commanders seeking to restructure or validate their allocation of instructors, classrooms, and equipment. ELCS

can also be used to examine many other scheduling decisions. A commander experiencing difficulties maintaining equipment could investigate the impact of increasing the minimum delay time between courses to conduct maintenance. A constraint for a four-week period of no starts to perform maintenance might also accomplish the same goal. The same constraint may be used to guarantee a period for instructor training or annual Marine Corps requirements such as the rifle and pistol range.

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II. LITERATURE REVIEW

Applications of operations research are found throughout the USMC manpower system. Planners use attrition, assignment, goal programming, and scheduling models to improve the efficiency of existing systems by predicting future needs and increasing the flow of training systems. This chapter highlights recent manpower and training related literature and draws comparison to this thesis.

USMC Manpower planners use attrition models to determine accession numbers that directly impact recruitment or hiring goals [Bicknell 2003]. USMC manpower planners also use Markov chain models to project personnel inventory levels based on attrition, promotion, and demotion rates [Bicknell 2003]. The only attrition calculations performed in ELCS occur within the model input. A small percentage of Marines (5-12%) are removed from the system between commencement of MCT and graduation. Historical data dictated these percentages, and they depend on the week commencement occurred.

Nguyen [1997] revises the attrition Markov model used by USMC manpower planners to forecast annual recruit classification requirements by MOS. This thesis uses the yearly classification requirements as end-state goals for the training conducted within the derived schedule. We enforce goals through elastic constraints that penalize deviations according to the magnitude of the violation.

Bolton [1998] develops an excel-based, enlisted inventory projection model to predict future end strength based on the Marine Corps' current composition by pay grade and years of service (YOS). The planning at that time only considered YOS and therefore failed to recognize the difference between an E-3 with four YOS and an E-5 with the same. Not only are they promoted or demoted to different levels, but a Marine's pay grade at the end of their service commitment undoubtedly impacts their decision to reenlist or access. This thesis uses accession data calculated from attrition models by USMC manpower planners as part of a formula to compute model input data.

Chng [1987] formulates an officer assignment linear program to assign Marine Corps officers to MOSs upon graduation from The Basic School (TBS). Although not

used, Chng's model optimizes MOS assignment with school schedules. Chng only groups officers in three distinct categories (recruited or rechanneled, restricted or unrestricted, air or ground). The combination of group categories impacts the assignable MOSs of each officer. The largest category is recruited/unrestricted/ground who are eligible to fill all MOSs except pilot and non-flight officer (NFO). Those designated by rechanneled or air are previously assigned and unchanged by the model. Restricted officers are assignable to a subset of the MOSs.

The assignment portion of ELCS differs by realistically accounting for constraints imposed by program codes. Where Chng's model contains a gross majority of officers qualified to fill all available MOSs, ELCS places strict MOS subsets on each program code and disallows crossover between them. Another difference from Chng is the relaxation of class sizes and classification goals in addition to the penalty structure for these deviations. Chng allows users to select one of three relaxation techniques before solving the model (Option 1: a minimum number to be assigned to every MOS from each TBS class, Option 2: same as Option 1 except an additional relation if an officer must wait longer than a user input amount, Option 3: same as Option 1 except MOS and TBS class combinations can be designated for relaxation). There are no penalties to the objective function for these relaxations and no maximum violation is enforced. Our model allows relaxation at every stage and permits violations if the penalty is less than the amount of man-weeks saved. Our model also penalizes violations differently based on their magnitude and places an upper bound on the violations magnitude (see penalty section).

Goal programming offers another method for solving personnel issues. Brown [2002] develops a model to reduce waste in the Army Reserve Initial Entry Training seats by reallocating seats among Army components. Brown's model decided the negotiating strategy of the Army Reserve, so school seats could be swapped among other Army components to best meet the predicted yearly seat demand. His model considers a fixed class schedule and decides how many students should start school or wait each week. Elastic variables track deviations from monthly, MOS, and training type goals. The objective function value is driven by violations of the established goals. Brown's

penalties are constant within most types of violations with under violations weighted heavier than over violations to force achievement of MOS classification goals.

Our model does not assume the classification goals must be precisely met. Instead, the model makes scheduling and assignment determinations based on the cost to the objective function in man-weeks. ELCS focuses on TAT, and we only consider constraint violations unacceptable if the preferred decision can be made in fewer weeks than the penalty's magnitude. We consider the total man-weeks lost to idle personnel the most important element in the objective function, but Brown's model only considers this variable in balance constraints. ELCS also differs in its treatment of the penalties.

Justice [1993] presents a scheduling model to determine yearly class schedules for the Marine Corps Communication-Electronics School. We believe the school currently schedules to maximum capacity without use of the product created by Justice. Justice focuses on a small subset of the Marines contained in this thesis. Unlike ELCS, which schedules and assigns Marines to the first school in their MOS pipeline, Justice schedules the entire sequence of classes a Marine must attend to qualify for their MOS. Both models strive to reduce the delay in the system by efficiently scheduling class starts while adhering to restrictions on class frequency and size.

Justice's model contained constant penalty values determined by the user and did not offer an explanation of reasonable values. He reports on several experiments of changing the penalty values to examine response changes, but the penalty values still retain a linear relationship. The results of these experiments are then given by the objective function value, which includes actual man-days delayed in the system plus penalties. ELCS reports results as actual delay time with the number of categorical violations annotated separately. We believe this method offers more useful information to planners.

Whaley [2001] presents two integer linear programs to optimize entry-level MOS school and recruit scheduling within the Marine Corps. The models decide weekly recruitment numbers by program and gender combinations, school start dates, and number of school attendees by gender and MOS pairs. Whaley identifies three potential opportunities for improvement. Our model explores the area we consider most

important: Provide a direct link between the Program Plan and MOS training school schedules. Whaley's models inspired this thesis, and there exists many similarities between the two. USMC planners considered Whaley's model too restrictive, largely due to his construction of an optimal weekly recruiting schedule. Their desire for a similar product that concedes to the current recruiting strategy led to our thesis treating recruiting data as input. Our work parallels and expands those concepts originally explored by Whaley.

III. ELCS

A. MODEL OVERVIEW

The goal of ELCS is to minimize TAT by recommending a fiscal-year schedule for the first entry-level school in each MOS pipeline and corresponding MOS assignment numbers for each class. ELCS links the Program Plan executed by MCRC with the Classification Plan executed by M&RA using an integer linear program. Using a Microsoft Excel input file, we convert the Program Plan into input data using historical Recruit Training commencement week to MCT graduation week percentage breakdowns and published fiscal-year recruit shipping schedules.

We attack this problem with an integer linear program to output an optimal school schedule and report the incurred TAT. The model minimizes the time awaiting training (TAT) with penalties assessed for violating class sizes and other elastic constraints. Elastic constraints allow the model to violate established goals, minimums, and maximums while incurring a penalty expressed as man-weeks in the objective function. Our penalties are piecewise linear approximations to nonlinear, convex functions. These penalty functions model higher penalty per unit as violation magnitude increases. By removing the penalties, we have the means to compare the TAT of different schedules and varying input. This technique allows decision makers to compare and contrast different options and their effect on TAT. The model also contains balance-flow equations and upper-bounds for the segments of the piecewise linear penalty functions.

ELCS uses four types of data: recruiting, MCT graduation distribution, school, and classification. Recruiting data comes from the Program Plan and the Weekly Shipping Plan. These sources allow us to estimate weekly arrivals at Recruit Training by gender and program. The historical distribution of recruits graduating from MCT ‘w’ weeks after Recruit Training commencement, coupled with the recruiting data, produces the expected weekly arrivals to the entry-level school system. School data constrains the problem by instituting minimum and maximum class size, frequency, and delay between consecutive classes. There are additional sources of class data, such as the earliest week in the fiscal year for the first class offering, based on computations of other input data.

Classification data is the final type used. Yearly MOS goals and over and under classification preferences constitute the preponderance of classification data. Each week, for every school, ELCS considers all constraints (formed from the data sources) and either starts a school with a group of Marines it assigns the MOS associated with the school or holds the Marines until the next week where it performs the same decision.

B. ASSUMPTIONS

ELCS uses the following assumptions:

- Recruiting Command meets the monthly Program Plan goals exactly.
- Recruiting Command ships Marines from all program codes to Recruit Training according to the weekly percentages published in the Weekly Shipping Plan.
- Historical data can predict the attrition of Marines and distribution of the time it takes Marines to complete Recruit Training and MCT. This distribution is consistent across all programs for each gender.
- Actual course starts and size limits of other Service schools used by Marines in FY2003 can be used as bounds for the same schools in FY2004.
- Marines can begin MOS training the week after MCT graduation.
- Additional courses in each MOS pipeline are optimally scheduled by each schoolhouse to commence upon the completion of the first course ELCS schedules.
- A MOS course's last start of the previous year has enough seats for all Marines waiting to attend that school. The initial data can be determined from expected arrivals after the last start.

C. INDICES

c	common course for multiple MOSs
g	gender
p	enlistment programs excluding infantry programs
r	range for piecewise linear penalty functions
s	MOSs excluding all infantry MOSs
w, w'	week

D. SETS

$grpMOS_c$	set of MOSs that attend common course *c*
gspec	set of MOSs that are male gender specific
$MOSgrp_p$	set of MOSs contained in enlistment program *p*
$ovStr_s$	set of MOSs declared over-strength in the Classification Plan

E. DATA

1. Personnel Requirements

$classify_{gs}$	number of Marines of gender *g* to classify into MOS *s* after Recruit Training. (Marines)
$initial_{gp}$	number of MCT graduates from program *p* of gender *g* waiting from the previous fiscal year to begin MOS training (Marines)
$recruit_{gpw}$	number of Marine recruits of gender *g* and program *p* to graduate from MCT and ready to begin MOS training on week *w* based on historical graduation distributions and recruiting strategy (Marines)

2. MOS Training School

$commonMin_c$, $commonMax_c$	minimum and maximum class size for common course *c* shared by multiple MOSs as the first school in their training pipelines (Marines)
$courseMin_s$, $courseMax_s$	minimum and maximum class size for the last school in the training pipeline for MOS *s* (Marines)
$eStart_s$	the earliest week MOS *s* can begin its first course of the year (based on last course start of previous year and $minDelay_s$) (weeks)
$length_s$	the length in weeks for restricting the number of concurrent courses in MOS *s* (weeks)
$maxAtOnce_s$	the maximum number of concurrent courses for MOS *s* scheduled during $length_s$ weeks (Starts)
$minDelay_s$, $maxDelay_s$	minimum and maximum delay between successive groups of Marines training for MOS *s* (weeks)
$minStart_s$, $maxStart_s$	minimum and maximum first course starts for groups of Marines training for MOS *s* (starts / year) Note: The model is infeasible if $minStart_s > 52 / maxDelay_s$
$minCStart_c$, $maxCStart_c$	minimum and maximum number of starts for common course *c* (starts / year)

3. Penalty

$pCommonOver_r$	penalty for violating the maximum class size of a common course over range *r* (Marine-weeks)
$pCommonUnder_r$	penalty for violating the minimum class size of a common course over range *r* (Marine-weeks)
$pCourseOver_r$	penalty for violating the maximum class size over range *r* (Marine-weeks)
$pCourseUnder_r$	penalty for violating the minimum class size over range *r* (Marine-weeks)
pMaxStart	penalty for violating the maximum number of class starts (Marine-weeks)
pOverInitial	penalty for the number of Marines, from a program, waiting at the end of the year in excess of the initial condition (Marine-weeks)
$pOverClassify_{rs}$	penalty for training too many Marines in MOS *s* over range *r* (Marine-weeks)
$pUnderClassify_{rs}$	penalty for training too few Marines in a MOS *s* over range *r* (Marine-weeks)
pUnderInitial	penalty for the number of Marine, from a program, waiting at the end of the year below the initial condition (used only when user wants the system to begin and end in nearly the same state) (Marine-weeks)

4. Violation Limits

$GrpOverLimit_{cr}$	maximum class size violation limit for common course *c* over range *r* (Marines)
$GrpUnderLimit_{cr}$	minimum class size violation limit for common course *c* over range *r* (Marines)
$OverLimit_{sr}$	maximum class size violation limit for MOS *s* over range *r* (Marines)
$OvUndClassify_{sg}$	minimum and maximum violation limit for classification of gender *g* into MOS *s* over range *r* (Marines)
$UnderLimit_{sr}$	minimum class size violation limit for MOS *s* over range *r* (Marines)

5. Other

$disc_w$	discount for week *w*

F. VARIABLES

1. Binary

$CSTART_{cw}$	1 if a group of Marines begins training for common course *c* at the beginning of week *w* , 0 otherwise
$START_{sw}$	1 if a group of Marines begins training for MOS *s* at the beginning of week *w* , 0 otherwise

2. Positive

$CMAXSTARTVIOL_{c}$	the number of common course *c* school starts above the maximum (Scalar)
$COMMONOVER_{cwr}$	the number of Marines exceeding the maximum class size of common course *c* during week *w* over range *r* (Marines)
$COMMONUNDER_{cwr}$	the number of Marines below the minimum class size of common course *c* during week *w* over range *r* (Marines)
$COURSEOVER_{swr}$	the number of Marines exceeding the maximum class size of MOS *s* during week *w* over range *r* (Marines)
$COURSEUNDER_{swr}$	the number of Marines below the minimum class size of MOS *s* during week *w* over range *r* (Marines)
$MAXSTARTVIOL_{s}$	the number of MOS *s* school starts above the maximum (Scalar)
$OPENTRAIN_{gsw}$	number of Marines with open contracts of gender *g* to begin training for MOS *s* at the beginning of week *w* (Marines)
$OVERCLASSIFY_{sgr}$	the number of Marines above the classification goal for gender *g* of MOS *s* over range *r* (Marines)
$OVERINITIAL_{gp}$	the number of Marines of gender *g* and enlistment program *p* waiting at the end of the fiscal year in excess of those waiting at the beginning of the year (ie. $WAIT_{g,p,52} - Initial_{pg}$, if > 0) (Marines)
$TRAIN_{gsw}$	number of Marines without open contracts of gender *g* to begin training for MOS *s* at the beginning of week *w* (Marines)
$UNDERCLASSIFY_{sgr}$	the number of Marines below the classification goal for gender *g* of MOS *s* over range *r* (Marines)
$UNDERINITIAL_{gp}$	the number of Marines of gender *g* and enlistment program *p* waiting at the end of the fiscal year in

excess of those waiting at the beginning of the year (ie. $Initial_{pg}$ - $WAIT_{g,p,52}$, if > 0) (Marines)

$WAIT_{gpw}$ — the number of Marines of gender g and enlistment program p who wait at during week w for the start of their MOS school class (Marine-weeks)

G. FORMULATION

1. Objective Function

$$
\begin{aligned}
&\textit{minimize } Z \qquad\qquad (\textit{in Marine-weeks units})\\
&Z = \sum_{gpw}(disc_w * WAIT_{gpw})\\
&+ \sum_{swr} \begin{matrix}(disc_w * pCourseUnder_r * COURSEUNDER_{swr}\\ + disc_w * pCourseOver_r * COURSEOVER_{swr})\end{matrix}\\
&+ \sum_{cwr} \begin{matrix}(disc_w * pCommonUnder_r * COMMONUNDER_{cwr}\\ + disc_w * pCommonOver_r * COMMONOVER_{cwr})\end{matrix}\\
&+ \sum_{gsr} \begin{matrix}(pUnderClassify_{rs} * UNDERCLASSIFY_{sgr}\\ + pOverClassify_{rs} * OVERCLASSIFY_{sgr})\end{matrix}\\
&+ pOverInitial * \sum_{gp} OVERINITIAL_{gp}\\
&+ pUnderInitial * \sum_{gp} UNDERINITIAL_{gp}\\
&+ pMaxStart * \sum_{s}(MAXSTARTVIOL_s + CMAXSTARTVIOL_s)
\end{aligned}
\tag{3.1}
$$

2. Constraints

$$WAIT_{gp'52'} \le initial_{gp} + OVERINITIAL_{gp} \qquad \forall\, g, p \tag{3.2}$$

$$WAIT_{gp'52'} \ge initial_{gp} - UNDERINITIAL_{gp} \qquad \forall\, g, p \tag{3.3}$$

$$recruit_{gp,w\text{-}1} + WAIT_{gp,w\text{-}1} = \sum_{s \in MOSgrp_p} (TRAIN_{gsw} - OPENTRAIN_{gsw}) + WAIT_{gpw} \qquad \forall\, g, p,\ w > 1 \tag{3.4}$$

$$initial_{gp} = \sum_{s \in MOSgrp_p} (TRAIN_{gsw} - OPENTRAIN_{gsw}) + WAIT_{gpw} \qquad \forall\, g, p \ne OPEN, w = 1 \tag{3.5}$$

$$recruit_{g,'OPEN',w\text{-}1} + WAIT_{g,'OPEN',w\text{-}1} = \sum_{s} OPENTRAIN_{gsw} + WAIT_{g,'OPEN'w} \qquad \forall g, w > 1 \tag{3.6}$$

$$initial_{g,'OPEN'} = \sum_{s} OPENTRAIN_{gsw} + WAIT_{g,'OPEN',w} \qquad \forall g, w = 1 \tag{3.7}$$

$$\sum_{g} TRAIN_{gsw} \leq START_{sw} * courseMax_{s} * 2 \qquad \forall s, w \tag{3.8}$$

$$\sum_{g} TRAIN_{gsw} \leq START_{sw} * courseMax_{s} + \sum_{r} COURSEOVER_{swr} \qquad \forall s, w \tag{3.9}$$

$$\sum_{g,s \in grpMOS_c} TRAIN_{gsw} \leq CSTART_{cw} * commonMax_{c} + \sum_{r} COMMONOVER_{cwr} \qquad \forall c, w \tag{3.10}$$

$$\sum_{g} TRAIN_{gsw} \geq START_{sw} * courseMin_{s} - \sum_{r} COURSEUNDER_{swr} \qquad \forall s,\ w \tag{3.11}$$

$$\sum_{g,s \in grpMOS_c} TRAIN_{gsw} \geq CSTART_{sw} * commonMin_{c} - \sum_{r} COMMONUNDER_{cwr} \qquad \forall c,\ w \tag{3.12}$$

$$\sum_{w'=w}^{w+minDelay_s-1} START_{sw'} \leq 1 \qquad \forall s, w \geq eStart_{s} \tag{3.13}$$

$$\sum_{w'=w}^{w+maxDelay_s-1} START_{sw'} \geq 1 \qquad \forall s, w \geq eStart_{s} \tag{3.14}$$

$$\sum_{w} START_{sw} \leq maxStart_{s} + MAXSTARTVIOL_{s} \qquad \forall s \tag{3.15}$$

$$\sum_{w} START_{sw} \geq minStart_{s} \qquad \forall s \tag{3.16}$$

$$\sum_{w} TRAIN_{gsw} \leq classify_{gs} - \sum_{r} UNDERCLASSIFY_{sgr} \qquad \forall g,\ s \tag{3.17}$$

$$\sum_{w} TRAIN_{gsw} \geq classify_{gs} + \sum_{r} OVERCLASSIFY_{sgr} \qquad \forall g,\ s \qquad (3.18)$$

$$START_{sw} \leq CSTART_{cw} \qquad \forall c, s \in grpMOS_c, w \qquad (3.19)$$

$$\sum_{w} CSTART_{cw} \leq maxCStarts_c + CMAXSTARTVIOL_c \qquad \forall c \qquad (3.20)$$

$$\sum_{w} CSTART_{cw} \geq minCStarts_c \qquad \forall c \qquad (3.21)$$

$$\sum_{w=w'}^{w'+length_s-1} START_{sw} \leq maxAtOnce_s \qquad \forall s \qquad (3.22)$$

3. Variable Bounds

$COURSEOVER_{swr} \leq OverLimit_{sr} \qquad \forall s, w, r$

$COURSEUNDER_{swr} \leq UnderLimit_{sr} \qquad \forall s, w, r$

$COMMONOVER_{cwr} \leq GrpOverLimit_{cr} \qquad \forall c, w, r$

$COMMONUNDER_{cwr} \leq GrpUnderLimit_{cr} \qquad \forall c, w, r$

$UNDERCLASSIFY_{sgr} \leq OvUndClassify_{sg} \qquad \forall s, g, r$

$OVERCLASSIFY_{sgr} \leq OvUndClassify_{sg} \qquad \forall s, g, r$

H. EQUATION DISCUSSION

Equation (3.1), the objective function, gauges TAT by use of a weighted function of the time Marines await the start of their MOS school and violations of school constraints. All penalties incurred in the objective function are in Marine-weeks.

Equations (3.2) and (3.3) account for Marines waiting within each program at the beginning and end of each fiscal year. If more or less Marines are present at the fiscal year's end, the elastic variable incurs a penalty in the objective function.

Balance constraints (3.4) and (3.6) guarantee the previous week's MCT graduates and waiting Marines equal the next week's MOS school attendees and waiting Marines within each program. Equation (3.6) differs from (3.4) because it only balances open contracts. Equations (3.5) and (3.7) are balance constraints for the fiscal year's first

week. They differ from (3.4) and (3.6) by using the initial condition of the system to balance the outflow in the first week.

Elastic constraints (3.9) and (3.11) ensure the number of Marines attending a course fall within the prescribed minimum and maximum class sizes. They permit violations at an expense to the objective function. Equation (3.8) ensures Marines can't be trained unless a school starts (we chose the coefficient 2 as an arbitrary number greater than the maximum allowable violation which is 1.2 or 20%). Elastic constraints (3.10) and (3.12) perform the same utility for common courses.

Equation (3.13) restricts the number of course starts in a sequential time period to one, based on the minimum delay time between starts.

Equation (3.14) requires at least one class start in a sequential time period, based on the maximum delay time between starts.

Elastic constraints (3.15) and (3.16) ensure the number of course starts fall between the allowable amounts. Violations of the maximum incur a penalty to the objective function, but breaches of the minimum are used to identify saturated curricula and not penalized.

Elastic constraints (3.17) and (3.18) steer the system toward the established classification goals.

Equation (3.19) starts a common course when a MOS that shares the course has a start occurrence (Note: a common course start does not require all sharing MOSs to start).

Equation (3.20) and (3.21) are identical to (3.15) and (3.16) but used to bound common course starts. Only upper bound violations incur penalty.

Equation (3.22) enforces the maximum number of concurrent courses a MOS school can handle.

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IV. PENALTIES

A. INTERPRETATION

ELCS penalties vary based on penalty type, discount factor, and section of the piece-wise linear function. Penalty values in ELCS represent decisions or, more precisely, lower bounds on the amount of TAT savings necessary before the violation becomes advantageous. For example, all other things being equal, a value of pCourseOver = 3 means a Marine will only attend an already full course if it reduces his wait time by at least three weeks. Decision-makers select penalty values after answering a simple question: "What TAT savings would make this option desirable?" The use of piece-wise linear penalty functions (discussed in this chapter) enable the decision maker to adjust the penalty value as the violation's magnitude increases.

B. PENALTY TYPES

First, we explore the significance of different types. In an environment with limited resources such as a training system, each type of violation puts a unique strain on the system. A violation of the maximum class size could create an unsatisfactory instructor-student ratio, exceed the amount of available training equipment, or surpass existing classroom space. On the other hand, a violation of the minimum class size takes up instructors and classrooms that could have been used for a larger class in the future. The inherent differences between the penalty types make selection of violation and penalty magnitudes important. Once again, the decision-maker should ask the fundamental question, "What TAT savings would make this option desirable," when selecting penalty values.

C. DISCOUNTING

Discount factors impact penalty magnitudes and influence model decisions [Newman, Brown, Dell, Giddings, Rosenthal 2000]. A discount factor penalizes violations more severely depending on when they occur. In ELCS, we penalize violations harsher at the beginning of the year. Discounting allows us to enforce closer adherence to the training system's rules early in the year. Moderate discount values break ties between two decisions that were equal before introducing discount values without significantly altering the results, while a more aggressive technique may push all

violations toward the end of the year. Discounting can reduce model run time. We use a discount factor on all objective function penalties indexed by week.

D. PIECE-WISE LINEAR FUNCTIONS

A piece-wise linear function allows the user to penalize in a nonlinear fashion while maintaining linearity in the model. Imagine taking a nonlinear function and breaking it into segments, numbering each segment in sequential order from an index. Now approximate each piece by a line segment with constant slope. You've just created a piece-wise linear function. The length of the n^{th} segment along the x-axis is the upper bound for the n^{th} elastic variable being penalized, and the penalty equals the segment's slope.

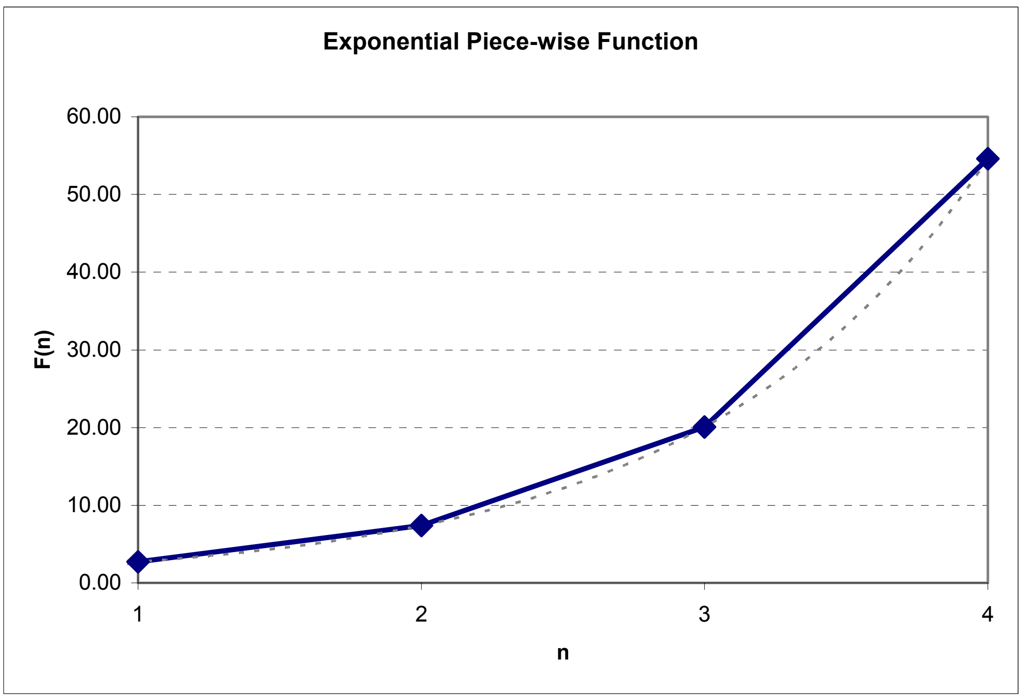

Figure 3. A Piece-wise Linear Approximation to an Exponential Function.
An example of an exponential penalty function using the piece-wise linear approximation where the penalty increases with each additional violation (all segments are of length 1). A violation of one would incur a penalty of 1.72 objective function units (the slope of the line segment from 0 to 1). A violation of two would incur a penalty of 6.39 (1.72 + 4.67). An index of 1 would indicate the first segment (0 to 1), index 2 (1 to 2), and so on. So, $pViolation_1 = 1.72$ and the variable $VIOLATION_1 \leq 1$, $pViolation_2 = 4.67$ and the variable $VIOLATION_2 \leq 1$, and so on.

E. STRICT ENFORCEMENT OF CONSTRAINTS

We consider some violations undesirable under any condition. For these instances, we select a penalty value greater than the maximum waiting time (i.e., if one year is the maximum wait time, then we select 53). This forces the model to strictly enforce the constraint and only allow violations under extreme conditions. Violation of a strictly enforced constraint provides the user with essential feedback regarding the training system. For example, the maximum number of courses started each year might be one such constraint. A violation would imply a potential problem with the system's capacity and warrants a deeper look at the impact of increasing the maximum number of starts or course size.

F. LOOSE ENFORCEMENT OF CONSTRAINTS

We consider some violations acceptable if they yield any savings. For these instances, we select a penalty value equal to one unit of the objective function. All other things being equal, this allows the model to violate an elastic constraint if it saves a Marine one-week of waiting time. Ten Marines attending a course, with a minimum course size of eleven, might be a useful situation for loose enforcement of a constraint. Although we have clearly violated the minimum course size, the expected strain incurred by the system is minimal. Tracking the total violations of a loosely enforced constraint suggests potential changes to the system. For instance, a course minimum frequently violated may suggest decreasing the course maximum in order to reallocate instructors to increase the frequency of the course.

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V. IMPLEMENTATION

A. DATA

1. Summary

ELCS uses data from the following Marine Corps planning documents: Classification Plan, Program Plan, Weekly Shipping Plan, MCO 1130.53P with change 1 (Enlistment Option Programs), FY2003 Master Course Schedule, Marine Corps Formal School Catalog, and Training Input Plan 2004 MOS Report. ELCS derives additional data not specifically stated within these documents (e.g., minimum course frequency).

We incorporate historical data to account for course information of other service schools. Historical data also provides a link between recruitment and MCT graduation.

ELCS imports data from Excel comma delimited files and text files when necessary. The comma delimited files originate from master Excel workbooks that allow interaction and automatic updates between worksheets.

2. Course Data

Each MOS school provides ELCS with seven data elements: maximum class size, minimum class size, maximum frequency, minimum frequency, minimum delay between starts, maximum delay between starts, and earliest start week (see Table 3). Maximum and minimum class sizes and maximum frequency are published in the Training Input Plan. Minimum frequency provides ELCS with a lower bound that appear to improve solution time. We establish minimum frequency by dividing the classification requirement (both genders combined) by the maximum class size. Maximum delay, the longest period allowed with no course starts, requires planner input. The minimum delay between starts can be established by the school to limit the number of concurrent classes held at any given time. We calculate the earliest start week as the week occurring minimum delay weeks after the last MOS course start from the previous year (see Table 4). All $START_{sw}$ variables with a week index less than the earliest start week are fixed to zero.

Schools run by other services publish minimums and maximums, but the Marine Corps students comprise a very small percentage of the attendees. For this reason, we

rely on historical quota distribution for data. Exploration of variations in quota distribution could provide guidance for future requests to other service schools.

S	course min	course max	maxNumberStarts	minNumberStarts	mindelay	maxdelay	eStart
0121	15	30	31	22	1	4	1
0151	15	30	30	25	1	4	1
0161	4	10	10	9	2	8	1
0231	20	30	9	6	4	12	3

Table 3. Example of MOS School Data Elements.
Seven essential elements of MOS school data: minimum and maximum course size, minimum and maximum course starts, minimum and maximum delay between starts, and earliest start week.

MOS	lastStart	mindelay	eStart
0121	48	1	1
0151	48	1	1
0161	49	2	1
0231	51	4	3
0261	28	27	3

Table 4. Earliest Start Calculation
We restrict each MOS by not allowing it to start its first course until a week greater than or equal to the earliest starting week ($eStart_s$).

Some MOSs share a common first course in their course sequence (depicted in Table 5). These occurrences change our treatment of the data. Instead of one MOS having a minimum and maximum course size equal to that of the course, we now sum across all MOSs sharing the course to ensure the total attending fall within the common course limits. Common courses provide ELCS with four essential data elements (see Table 6) because the minimum and maximum delay and earliest start are already accounted for by each MOS sharing the course.

S	A1635X1	M092471	M0925U1	M092721	M09BND1	N236482	N236982
0612	0	1	0	0	0	0	0
0613	0	0	0	0	0	0	0
0614	0	1	0	0	0	0	0
0621	0	0	1	0	0	0	0
0622	0	0	1	0	0	0	0
0626	0	0	1	0	0	0	0
0627	0	0	1	0	0	0	0
0651	0	0	0	0	1	0	0
0656	0	0	0	0	1	0	0
0811	0	0	0	0	0	0	0

Table 5. Example of Set $grpMOS_{sc}$
A sample of the set $grpMOS_{sc}$, where 1 indicates the common course is first in the MOS' training sequence.

Common course c	Min freq	Max freq	Min size	Max size
A1635X1	30	47	20	60
M092471	14	19	20	30
M0925U1	25	36	20	55
M092721	22	27	10	24
M09BND1	15	33	20	30
N236482	23	27	5	9
N236982	36	50	5	9
N2373C2	11	32	8	35
N23E2X2	31	50	12	40
N23G3U2	30	45	8	15
N23WSG2	43	48	8	14
N23WSJ2	25	29	1	2

Table 6. Common Course Data Elements
Data elements required for common courses. Minimum delay, maximum delay, and earliest start are unnecessary because they are particular to each MOS and not the common course.

We assumed earlier that the entire MOS pipeline could be scheduled according to the first course in the pipeline, but if we send too few Marines from a MOS to a common course there are not enough to begin a course later in their sequence. To avoid that situation, we determine the minimum and maximum class size for a MOS sharing a common first course by the final course in its training sequence. The final course also

determines the maximum number of course starts, and the minimum number of starts follows from the same simple mathematical equation used for an individual MOS.

3. Violations

Elastic constraints play an integral part of any optimization problem. We consider violations and their respective penalties using piece-wise linear functions. They better depict the nonconstant behavior inherent to a system where larger violations become increasingly less desirable. We chose a range of ten levels, where violation of all ten levels attains the maximum allowable violation. We chose penalties according to the criteria established in Chapter 4, and they are always increasing with range *r* (see Table 7).

r	pCourseUnder	pCourseOver	pGroupUnder	pGroupOver	pUnderClassify	pOverClassify
r1	2	3	1	3	1	1
r2	2	4	1	4	2	1
r3	3	6	2	6	2	1
r4	3	6	2	6	2	2
r5	4	8	3	8	2	2
r6	4	8	3	8	4	3
r7	6	9	4	9	4	3
r8	7	10	4	10	5	3
r9	8	12	6	12	6	5
r10	8	14	7	14	8	5

Table 7. Piece-wise Penalty Values.
Penalty values increase as the range *r* increases. A violation of the minimum course size (variable $COURSEUNDER_{sw1}$) in range r1 costs two Marine-weeks (penalty $pCourseUnder_1$), while a violation in range r10 (variable $COURSEUNDER_{sw10}$) costs eight Marine-weeks (penalty $pCourseUnder_{10}$). The penalties remain constant over all weeks (w), common courses (c), and MOSs (s) because the violation magnitudes are established as percentages of the minimum and maximum preferred limits. The penalties for $pUnderClassify_{rs}$ and $pOverClassify_{rs}$ double for $s \in crit_s$ and $s \in ovStr_s$ respectively.

We impose upper bounds on the amount of violations allowed over the range (r) of the piece-wise linear function (see Tables 8-11). All limits stay constant over all weeks because discounting enforces the user's preferences for the time of year violations occur. Changing the size of the range indices impacts program run time and should be lowered to reduce run time or enlarged to increase resolution.

C	r1	r2	r3	r4	r5	r6	r7	r8	r9	r10
A1635X1	1	1	2	1	1	1	1	2	1	1
M092471	1	0	1	0	1	1	0	1	0	1
M0925U1	1	1	1	1	2	1	1	1	1	1
M092721	0	1	0	1	0	1	0	1	0	1
M09BND1	1	0	1	0	1	1	0	1	0	1
N236482	0	0	1	0	0	0	0	0	1	0
N236982	0	0	1	0	0	0	0	0	1	0
N2373C2	1	0	1	1	1	0	1	1	0	1
N23E2X2	1	1	0	1	1	1	1	0	1	1
N23G3U2	0	1	0	0	1	0	0	0	1	0
N23WSG2	0	1	0	0	0	1	0	0	1	0
N23WSJ2	0	0	0	0	0	0	0	0	0	0

Table 8. GrpOverLimit$_{cr}$

The upper bound of common course overages per section of the piece-wise linear function for the variable GROUPOVER$_{cwr}$, expressed in Marines. Each segment represents an additional 2% overage of the course's maximum class size with a maximum allowable overage of 20%. The limits remain constant over all weeks (w).
Example: $GROUPOVER_{A1635X1,w,r3} \leq 2$, for all w

C	r1	r2	r3	r4	r5	r6	r7	r8	r9	r10
A1635X1	1	1	1	1	1	1	1	1	1	1
M092471	1	1	1	1	1	1	1	1	1	1
M0925U1	1	1	1	1	1	1	1	1	1	1
M092721	1	0	1	0	1	0	1	0	1	0
M09BND1	1	1	1	1	1	1	1	1	1	1
N236482	0	1	0	0	0	1	0	0	0	1
N236982	0	1	0	0	0	1	0	0	0	1
N2373C2	0	1	0	1	0	0	1	0	1	0
N23E2X2	1	0	1	0	1	1	0	1	0	1
N23G3U2	0	1	0	1	0	0	1	0	1	0
N23WSG2	0	1	0	1	0	0	1	0	1	0
N23WSJ2	0	0	0	0	0	0	0	0	0	1

Table 9. GrpUnderLimit$_{cr}$

The upper bound of common course underages per section of the piece-wise linear function for the variable GROUPUNDER$_{cwr}$, expressed in Marines. Each segment represents an additional 5% underage of the course's minimum class size with a maximum allowable underage of 50%. The limits remain constant over all weeks (w).
Example: $GROUPUNDER_{A1635X1,w,r10} \leq 1$, for all w

S	r1	r2	r3	r4	r5	r6	r7	r8	r9	r10
0612	1	0	1	0	1	1	0	1	0	1
0613	0	0	0	0	0	0	0	0	1	0
0614	0	0	1	0	0	0	1	0	0	0
0621	1	1	1	1	2	1	1	1	1	1
0622	1	0	1	0	1	1	0	1	0	1

Table 10. Example of $OverLimit_{sr}$
The upper bound of MOS course overages per section of the piece-wise linear function for the variable $COURSEOVER_{swr}$, expressed in Marines. Each segment represents an additional 2% overage of the course's maximum class size with a maximum allowable overage of 20%. The limits remain constant over all weeks (w).
Example: $COURSEOVER_{0612,w,r1} \leq 1$ and $COURSEOVER_{0612,w,r2} \leq 0$, for all w

S	r1	r2	R3	r4	r5	r6	r7	r8	r9	r10
0121	1	1	0	1	1	1	0	1	1	1
0151	1	1	0	1	1	1	0	1	1	1
0161	0	0	1	0	0	0	0	1	0	0
0231	1	1	1	1	1	1	1	1	1	1
0261	0	0	0	0	0	0	0	0	0	1

Table 11. Example of $UnderLimit_{sr}$
The upper bound of MOS course underages per section of the piece-wise linear function for the variable $COURSEUNDER_{swr}$, expressed in Marines. Each segment represents an additional 5% underage of the course's minimum class size with a maximum allowable underage of 50%. The limits remain constant over all weeks (w).
Example: $COURSEUNDER_{0231,w,r6} \leq 1$, for all w

4. MOS Classification

Under perfect conditions, the number of Marines recruited according to the Program Plan would equal the total number of Marines required to fill the Classification Plan. Unfortunately, approximately 8% of recruited Marines don't reach their MOS school. The projected year's MCT output exceeded the FY2003 classification data used for this model by 1,825 Marines. Carryover from the previous year (1,417 Marines) also interfered with the model's ability to exactly meet the classification goals set in the plan. If our model trained every available Marine under these circumstances, we expect to classify 15.5% more than needed. For these reasons, it is necessary to penalize for differences between the initial conditions and Marines waiting at year's end. We use strict enforcement of the constraint to ensure Marines waiting from each program do not

exceed the initial conditions. Because it would be desirable to have less Marines waiting at the end of the fiscal year, we selected a moderate penalty for this violation. By using a moderate penalty (2-3 man-weeks), we encourage the system to train a large portion of extras while not ending the year with an empty queue. This technique allows us to transition more slowly to an optimized, stable system.

s	g	classify
0121	male	576
0151	male	640
0161	male	73
0121	female	70
0151	female	92
0161	female	10

Table 12. Example of $classify_{sg}$
The $classify_{sg}$ data comes from the Classification Plan. ELCS attempts to meet the classification goal and prefers to exceed the required amount instead of falling short. However, ELCS considers some MOSs overstrength and allocates extra Marines accordingly.

s	g	r1	r2	r3	r4	r5	r6	r7	r8	r9	r10
0121	**male**	6	6	5	6	6	6	5	6	6	63
0151	**male**	6	7	6	7	6	6	7	6	7	70
0161	**male**	1	0	1	1	1	0	1	1	1	8
0231	**male**	1	2	1	2	1	2	1	2	1	16
0261	**male**	0	0	1	0	0	0	0	0	1	2

Table 13. $OvUndClassify_{sg}$
Over and under classification limits of the piece-wise linear function for the variables $UNDERCLASSIFY_{sgr}$ and $OVERCLASSIFY_{sgr}$. Each segment, except segment r10 (11%), represents an additional 1% overage or underage of the course's maximum class size with a maximum allowable overage or underage of 20%. The limits remain constant over all weeks (w).
Example: $UNDERCLASSIFY_{0121,male,r3} \leq 5$ and $OVERCLASSIFY_{0121,male,r3} \leq 5$

s	overStrength	critical
0121	0	0
0151	0	0
0161	0	0
0231	0	0
0261	1	0

Table 14. Sample of $ovStr_s$ and $crit_s$

Using $ovStr_s$ and $crit_s$ increases the model's desire to more closely meet the classification goal of particular MOSs and penalize violations above or below more severely. ELCS uses $ovStr_s$ in its current form but can easily be modified to incorporate $crit_s$. Example: $ovStr_{0261} = 1$, so classifying more Marines into MOS 0261 than specified in the classification plan would be penalized heavier than MOS 0121 and 0151.

5. Initial

We must consider the initial condition of the system where our schedule begins. This requires predicting the personnel in the system at a later date, because the master schedule could be made up to a year in advance and not the day before execution. We use the previous year's last starts for each MOS within a program to determine the program's initial data. Using the Classification Plan, we determine each MOS's percentage of the total number of classifications in the program. These percentages enable us to weight the impact of each last start. The summation of the MOSs in the program equals the initial data.

s	Male	female
AE	21	3
AF	62	3
AG	34	0
AJ	14	0
BA	26	1

Table 15. Example of $initial_{sg}$

The expected number of MCT graduates, by program code and gender, from the previous fiscal year still waiting to attend a MOS school on the first day of the year being scheduled. On October 1, 2003, we expected 21 males and 3 females from program AE to still require assignment to their MOS school.

In order to establish initial conditions, we again assume that MCRC will meet the goals set forth by the Program Plan and weekly shipping percentages are equal across all

programs. We gather the last scheduled school start for each MOS from the current master schedule. Using the Classification Plan, we determine each MOS' percentage of their program code. We add the $recruit_{gsw}$ values for all weeks after the last start and use the weight of the program percentage to determine the contribution to the initial data by each MOS. A similar procedure determines the initial conditions for open contracts.

s	p	Classify	PEF Total	MOS% Of PEF	MOS% Of OPEN	Last Start	sum recruit (g,w,s)	init Male PEF	init Fem PEF	Male open	Fem open
0121	CB	646	1616	39.98%	3.10%	w48	41	16	4	14.6	0.8
0151	CB	732	1616	45.30%	3.51%	w48	41	19	6	16.5	0.9
0161	CB	83	1616	5.14%	0.40%	w49	37	2	0	1.5	0.1
0231	DD	158	379	41.69%	0.76%	w51	11	5	1	1.8	0.1
0261	DD	21	379	5.54%	0.10%	w28	117	6	1	1	0.1

Table 16. Example of Initial Data Calculations.
This table contains the essential data for calculating the expected initial conditions. The $initial_{male,p}$ equals the sum of the init Male PEF column for all MOSs sharing a program code (i.e. PEF code).
Example: $initial_{male,CB}$ = 16 + 19 + 2 + init Male PEF for any additional CB

6. Recruiting

Information from several Marine Corps planning documents and historical data merge within Microsoft Excel to create $recruit_{gpw}$ data (See Table 17). From the Program Plan, we know the monthly program goals by gender. MCRC provides a shipping plan that establishes the weekly shipping goals by total recruits (not program specific). We extract weekly shipping percentages from this plan and apply them to the Program Plan. By combining these two documents, we break the Program Plan into an expected weekly shipment by program. This first transformation yields expected weekly input into recruit training, but we require a second transformation to generate expected weekly output from MCT. Historical pairings of ship week with MCT graduation week yields a representative distribution of weeks to complete pre-MOS training given a ship week (see Figure 4).

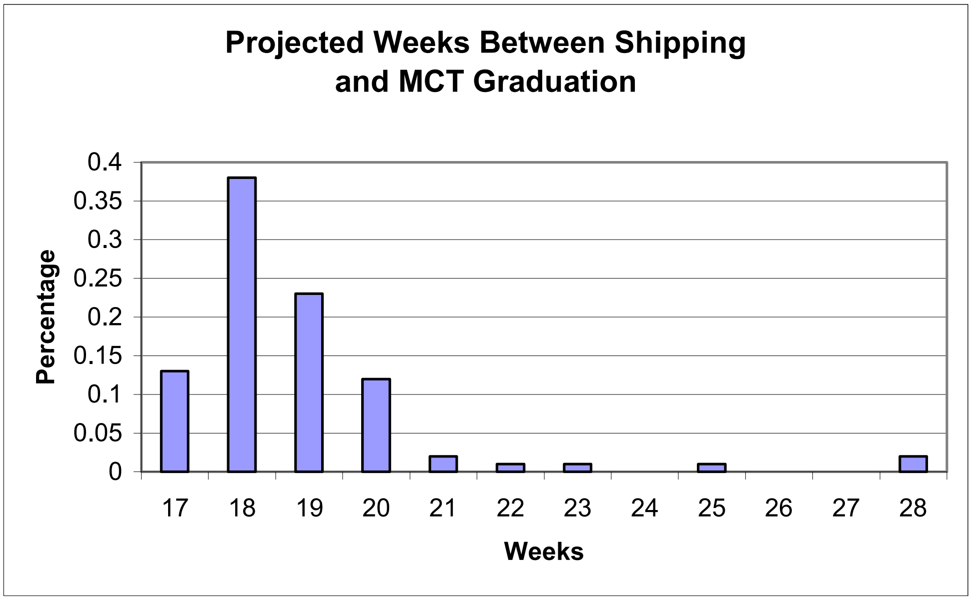

Figure 4. Projected Weeks Between Shipping and MCT Graduation.
The histogram shows the historical percentage of Marines graduating from MCT on the given week after shipping to Recruit Training during week one. ELCS uses historical percentages for each shipping week in the year to determine the each week's expected output from MCT (used to determine initial_{gp} and recruit_{gpw}). For example, if 100 Marines shipped to Recruit Training during week one of the fiscal year, we expect that 13 Marines will graduate MCT on the 17^{th} week, 38 on the 18^{th} week, and so forth. (Figure from Whaley, 2001)

g	p	w1	w2	w3	w4	w5	w6	w7	w8	w9	w10
male	AE	21	23	24	22	19	18	27	31	33	34
male	AF	37	44	45	48	43	41	57	66	71	74
male	AG	7	8	8	7	7	7	9	10	11	11
male	AJ	6	7	7	7	6	6	8	9	10	10
male	BA	20	22	22	22	19	18	26	30	31	33

Table 17. Example of recruit_{gpw}
ELCS uses $\text{recruit}_{gp,w-1}$ and $\text{WAIT}_{gp,w-1}$ to determine input into each week's balance constraint. An excel database calculates recruit_{gpw} according to information found in the Program Plan, the combined shipping percentages obtained from the weekly shipping plans of both the Eastern and Western Recruiting Region, and historical MCT graduation time (see Figure 4).

B. DATA INCONSISTENCY

1. Course Capacity

School data should be scanned to determine if the requirements exceed the system's capacity. The data obtained from the Training Input Plan for FY2003 shows 6 capacities (maximum frequency times maximum size) of the 185 MOSs that fall below the Classification Plan. Three of these MOS schools offer less than half the required seats. Within ELCS, the user must decide how to deal with courses unable to train the required amounts as they could lead to infeasibility if violation bounds are set using defaults. The author adjusts the maximum number of course offerings until maximum capacity fell within one Marine of the Classification Plan. This adjustment ensures the Marines recruited to fill these MOSs do not classify into MOSs already overfilled and suggests the optimal school dates if the system becomes able to handle the required capacity. This thesis does not consider students arriving to MOS courses from sources outside of MCT (e.g., Marine Corps Reserves, lateral transfers). Although these Marines make up a small percentage of overall training seats, they could impact courses with maximum capacities close to the classification goals.

2. Multiple Training Sequences

Of the 185 MOSs, 32 have multiple training sequences that lead to designation of their MOS. Three main reasons exist for the differences among an MOS' training sequence: trainees split later in the sequence to different coasts to attend their final course (see Figure 5), an additional course at the end of the standard sequence (see Figure 6), and a MOS shared by different aircraft type (see Figure 7). These instances occur with frequency nineteen, eight, and five respectively.

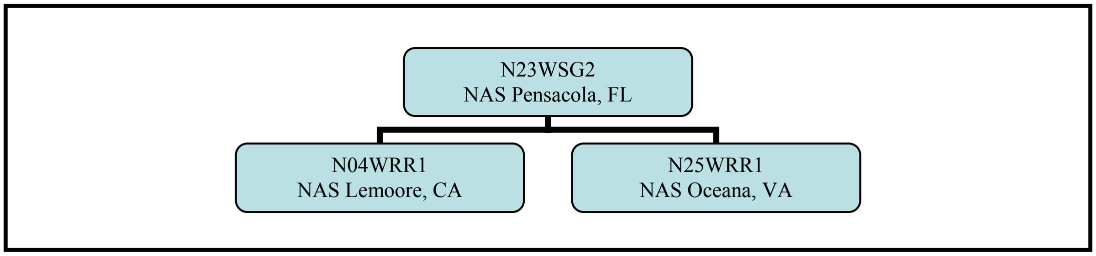

Figure 5. Multiple Training Sequences for MOS 6062 Due to Duty Station Coast

We found the courses on both coasts have nearly identical limits on size. Therefore, the author combines the frequency of both courses and treats them as one within the model. ELCS' solution schedule would not differentiate which of the two schools should be taught on each recommended MOS course start week. A simplistic approach would be alternating starts between the two schools, but school representatives should handle any such division.

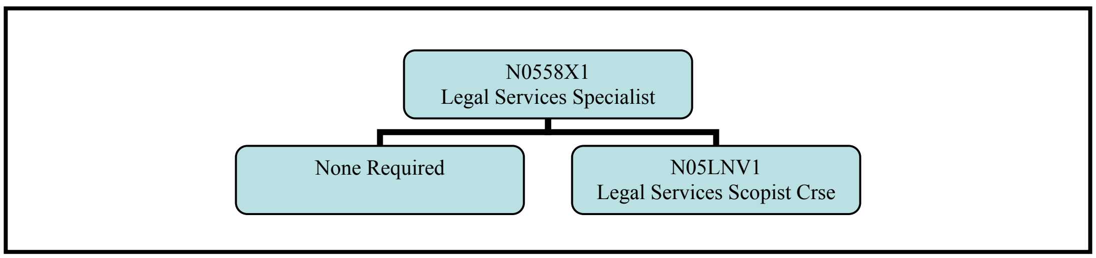

Figure 6. Multiple Training Sequences for MOS 4421 Due to Additional Course

This situation causes little concern as the additional course should begin immediately after graduation.

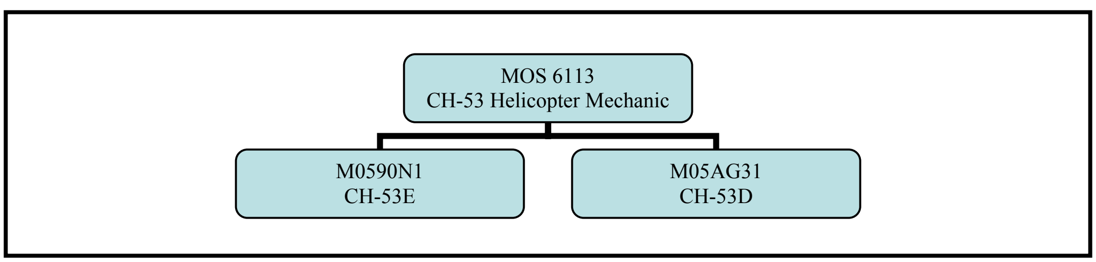

Figure 7. Multiple Training Sequences Due to Aircraft Type

Treatment of sequence differences due to aircraft type parallel those concepts applied to the different coasts.

3. Common Courses Later in Sequence

Three common courses, by our earlier definition, appear later in the training sequence of other MOSs. In two cases, N236982 and M09BND1, the later appearances account for only 10% of that course's attendees, but the later occurrence of M05WNA1

accounts for 54% of the course's yearly attendance. We assume the impact negligible in all cases. Reduction of the maximum class size offers one solution to ensuring open training seats.

C. COMPUTATIONAL TOOLS USED

ELCS uses the General Algebraic Modeling System (GAMS) [Brooke, Kendrick, Meeraus, and Ramam 1998] for implementation. All model run times are for a Pentium IV, 2 gigahertz Dell desktop computer with Windows 2000 operating system and 1.05 gigabyte of Random Access Memory (RAM) using CPLEX 9.0 [ILOG 2003] solver. ELCS has approximately 55,000 constraints, 234,000 positive and 9,500 binary variables. Solving for a 20% gap takes 27 hours, while only a 19% gap results after 83 hours.

D. CASCADE IMPLEMENTATION

We embrace the cascade technique as a means to reduce model run time. A cascade sequentially considers overlapping subsets of a model's time periods or other ordinally defined set [Baker 1997]. When using the cascade technique, the model undergoes an iterative solution process where integer variables divide into three settings: fixed, integer, or continuous. The first solution attempt holds no variables fixed and establishes the integer and continuous subsets based on a cutoff point in the ordinal set. In ELCS, the total classification goal for the MOS *s* dictates which group each of the start variables joins. At the end of the run, ELCS fixes the solution to the integer subset and refines the set's cutoff point for the next iteration. This repeats according to the number of cutoff points used by the modeler. ELCS runs in four iterations with cutoff points $\sum_{g} classify_{sg} \leq$ 30, 75, and 150.

We introduce the following new notation for a cascade implementation of ELCS.

cont_s	set of MOSs using $\mathrm{CONTSTART}_{sw}$ during cascade solving method (set updated at each iteration)
$\mathrm{CONTSTART}_{sw}$	continuous version of the START_{sw} binary variable used for cascade solving method

Implement the cascade by replacing START_{sw} with $\mathrm{START}_{s \in \mathrm{cont}_s, w} + \mathrm{CONTSTART}_{s \notin \mathrm{cont}_s, w}$ throughout the formulation.

E. MODEL VARIATIONS FOR POLICY EXPLORATION

1. Explanation

ELCS offers policy makers many opportunities to explore potential allocation or removal of resources. For instance, a schoolhouse plans to increase its instructor base and offer more course starts. How should the decision maker allocate the new offerings? One solution may stem from a myopic view of the system, where the course that usually runs at near capacity seems the obvious choice. However, this may not consider the true happenings of the system nor does it address the impact of additional instructors on potential reduction of minimum delay between starts or maximum concurrent courses. From a larger perspective, the Marine Corps might examine where instructor need is greatest to reduce TAT. We use generic modification of the current formulation to explore several potential training system issues in the following sections (modified constraints are differentiated with alphabetic identifiers).

2. Increasing Course Frequency

$EXTRASTARTS_s$	integer variable for additional starts offered penalty free above the maximum
additionalStarts	scalar for the total number of additional starts

$$\sum_{w} START_{sw} \leq maxStart_s + MAXSTARTVIOL_s + EXTRASTARTS_s \quad \forall s \tag{3.15a}$$

$$\sum_{s} EXTRASTARTS_s \leq additionalStarts \tag{3.23}$$

3. Increasing Maximum Class Size

$INCRCRSSIZE_s$	binary variable, 1 if MOS s will increase its maximum course size, 0 otherwise
incrCrsSizePercent	percentage increase to the current maximum course size
maxIncrCrsSize	maximum number of courses with increased course size

$$\begin{aligned}&\sum_{g} TRAIN_{gsw} \leq \sum_{r} COURSEOVER_{swr} + \\ &(START_{sw} + INCRCRSSIZE_s * incrCrsSizePercent) * courseMax_s \quad \forall s, w\end{aligned} \tag{3.9a}$$

$$\sum_{s} INCRCRSSIZE_s \leq maxIncrCrsSize \tag{3.24}$$

4. Maintenance or Training Standdown

The author foresees times in the training cycle when a break for maintenance or training may be necessary. Fixing consecutive start variables to zero allows the user an easy way to determine the TAT impact. There are constraints available to determine the best time of year for a break in training.

5. Program Plan Adjustments

ELCS handles Program Plan adjustments in its data calculations and requires no additional constraints. In this case, educated adjustments present the opportunity for improvement and recommendation for change, but blind exploration would be time-consuming and ill-advised. ELCS output suggests areas for improvement by identifying the average TAT by program. The author recommends use of the models implemented by Whaley for optimization of recruiting strategy in parallel with school scheduling.

6. Sequencing Courses

Additional work could be accomplished on our model to consider the sequencing of all courses within each MOS pipeline. This was considered during the formulation of the current model but left up to each schoolhouse to schedule secondary schools based on the model's recommendation for the first course in the sequence.

F. RESULTS

ELCS outputs an optimized, weekly MOS school master schedule (see Table 18) with suggested attendance by gender and MOS (see Table 19), which directly implies weekly MOS classification by gender. Secondary output of ELCS includes additional resource allocation or reduction recommendations when relevant, average TAT by enlisted option program (see Table 20), unused course offerings (see Table 21), and violation summaries. Table 22 contains a summary of results from ELCS. Figure 8 shows the impact of MCT graduation on $TRAIN_{gsw}$. Figure 9 depicts the course size violations by week. The information in Figure 9 proves most useful when compared with trends in Figure 8; however, we project the data on a separate figure due to scale differences. Figure 10 shows a by week comparison between $TRAIN_{gsw}$ and $WAIT_{gpw}$.

s	w1	w2	w3	w4	w5	w6
0121	1	1	1	1		
0151	1	1	1	1	1	
0161	1	1	1			
0231	1					

0411	1	1				
0431	1					
0451	1	1				
0481	1	1				

Table 18. Example Master Schedule Output
ELCS outputs a MOS course master schedule showing which schools should start classes each week. For example, the school for MOS 0121 starts courses on weeks 1-4 and does not start a course in weeks 5 and 6.

	WAIT	START	TRAIN male	TRAIN female
0651.w31	12			
0651.w32		1	7	1
0651.w33	6			
0651.w34		1	6	3
0651.w35	4			

Table 19. Example of Projected School Attendance
ELCS output of school starts and desired attendance by MOS and gender. For example, MOS 0651 should begin a school on week 32 with seven males and one female. Twelve Marines are waiting for a school from the program containing MOS 0651 in week 31.

p	**TOTAL TAT**	**TRAINED**	**Average**
AE	191	802	0.24
AF	642	1748	0.37
AG	206	386	0.53
AJ	123	331	0.37
BA	49	1480	0.03
BX	216	558	0.39
BY	289	748	0.39
CA	192	1936	0.1
CB	408	2026	0.2
CC	81	1282	0.06
CD	387	1289	0.3
CE	1190	1182	1.01
CF	47	460	0.1
CG	215	89	2.42
CH	45	72	0.62
CJ	469	1026	0.46
CK	910	337	2.7
CL	645	351	1.84
CM	121	1514	0.08

CN	110	694	0.16
DB	149	2250	0.07
DC	72	197	0.37
DD	200	430	0.47
G6	61	442	0.14
UJ	698	213	3.28
UT	245	631	0.39
U2	144	146	0.99

Table 20. Average Weeks of TAT by Program

ELCS outputs the average TAT by program. This format shows the user which programs incur the largest amount of TAT and highest average TAT. For example, program UT accumulates 245 weeks of TAT during the year for the 631 Marines trained at its MOS schools. This results in an average TAT of 0.39 weeks per Marine for the UT program.

s	Min	Actual	Max	s	Min	Actual	Max	s	Min	Actual	Max
0121	22	27	31	**3043**	21	26	40	**6223**	7	7	7
0151	25	30	30	**3051**	17	27	31	**6226**	2	3	4
0161	9	10	10	**3052**	2	2	3	**6227**	13	17	17
0231	6	8	9	**3112**	7	8	8	**6252**	8	12	12
0261	1	2	2	**3381**	21	38	41	**6253**	6	9	10
0411	5	8	8	**3432**	7	9	9	**6256**	5	6	6
0431	6	8	8	**3451**	3	3	4	**6257**	10	30	30
0451	15	17	17	**3521**	24	25	30	**6276**	6	10	10
0481	7	8	10	**3531**	22	45	47	**6282**	10	10	10
0511	3	5	6	**3533**	20	23	24	**6283**	4	4	4
0612	11	16	19	**4341**	7	8	9	**6286**	3	3	3
0613	15	20	20	**4421**	3	3	4	**6287**	12	12	12
0614	8	11	13	**4611**	3	6	6	**6312**	7	9	9
0621	21	32	36	**4612**	1	1	3	**6313**	5	8	8
0622	6	8	10	**4641**	4	13	13	**6314**	5	5	5
0626	3	4	4	**4671**	5	8	8	**6316**	3	3	3
0627	8	9	9	**5500**	5	16	16	**6317**	22	32	32
0651	7	22	33	**5711**	3	5	4	**6322**	7	11	11
0656	20	23	28	**5811**	10	26	26	**6323**	13	15	15
0811	5	8	8	**5831**	6	9	9	**6324**	12	16	16
0842	6	9	9	**5937**	4	4	6	**6326**	3	3	3
0844	7	12	12	**5942**	3	4	4	**6332**	6	8	8
0847	3	3	3	**5952**	6	7	8	**6333**	5	7	7
0861	4	6	6	**5953**	7	8	8	**6336**	3	3	3
1141	5	6	8	**5954**	6	8	8	**6337**	18	23	23
1142	6	7	9	**5962**	3	4	4	**6386**	7	12	12
1161	21	23	30	**5963**	3	3	3	**6412**	14	15	15
1171	6	8	9	**6042**	5	6	6	**6413**	17	18	18
1316	8	12	14	**6046**	17	23	29	**6423**	17	26	31
1341	24	30	51	**6048**	26	32	37	**6432**	5	8	8
1345	28	35	50	**6062**	5	11	11	**6433**	7	7	7
1361	7	9	11	**6072**	21	22	22	**6461**	11	18	18
1371	18	24	30	**6073**	14	14	14	**6462**	9	15	15
1391	18	22	26	**6074**	2	2	3	**6463**	2	3	6
1812	2	3	4	**6092**	19	22	22	**6464**	10	10	10
1833	10	12	16	**6112**	7	10	9	**6466**	3	6	6
2111	37	43	48	**6113**	8	11	10	**6467**	8	8	8
2131	6	8	8	**6114**	13	15	15	**6482**	12	15	15
2141	5	5	6	**6116**	4	5	4	**6483**	9	9	9
2146	7	8	9	**6122**	6	6	8	**6484**	7	8	8
2147	7	11	16	**6123**	4	6	6	**6492**	22	28	36
2161	8	11	14	**6124**	10	13	13	**6493**	2	3	3
2171	10	11	18	**6132**	5	5	5	**6531**	21	37	45
2311	27	39	44	**6152**	8	10	10	**6541**	14	34	45
2621	21	31	46	**6153**	10	12	12	**6672**	12	17	18
2631	8	8	8	**6154**	14	17	17	**6694**	4	6	7
2651	25	25	29	**6156**	5	5	5	**6821**	12	22	36
2671	12	14	14	**6172**	7	11	11	**7011**	3	5	5
2673	8	12	12	**6173**	10	11	12	**7041**	6	10	10
2674	7	9	9	**6174**	6	7	7	**7051**	27	40	40
2676	8	10	10	**6176**	5	7	7	**7212**	5	6	7
2822	5	6	7	**6212**	9	10	10	**7234**	3	3	3
2831	2	2	4	**6213**	3	7	7	**7242**	4	3	4
2844	9	13	13	**6214**	3	3	3	**7257**	39	47	48
2846	5	7	7	**6216**	4	8	8	**7314**	10	10	10
2847	11	11	11	**6217**	29	35	35	**7372**	2	3	3
2881	4	5	6	**6222**	4	4	4	**7382**	6	6	6
2887	2	2	3								

Table 21. Minimum, Maximum, and Actual Course Starts

ELCS outputs the minimum, maximum, and actual course starts by MOS. Through optimal scheduling, ELCS left 258 course offerings unused. For example, MOS 2621 has a maximum frequency of 46 and a minimum frequency of 21 that was determined by maximum class size and classification goal. ELCS chose to only start the course 31 times thereby leaving 15 offerings unused.

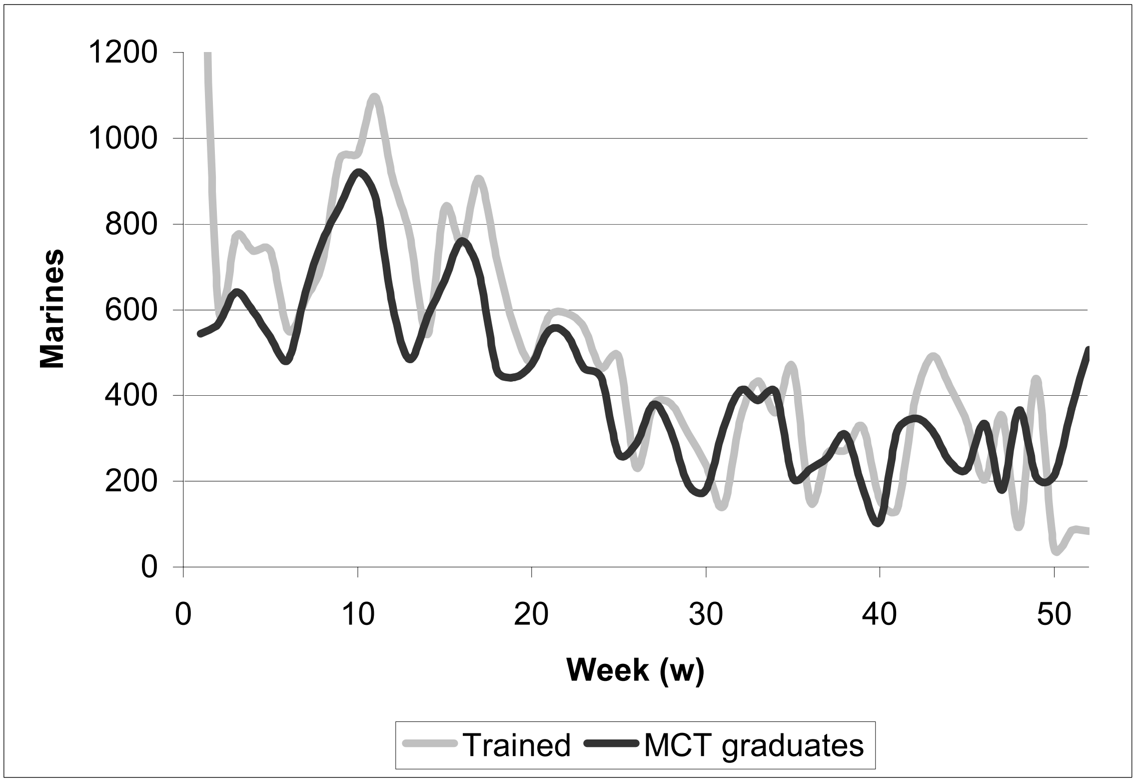

Figure 8. Projected MCT Graduates Impact on MOS School Arrivals
The graph depicts the impact of projected MCT graduates ($recruit_{gpw}$) on MOS school arrivals ($TRAIN_{gsw}$). We train a large number of Marines in week one because of a large initial population and graduates from the summer recruiting period. For this run of the model, we train very few Marines in weeks 50-52 because of a value of 2.5 for pUnderInitial (discussed in Chapter V, Section A-4).

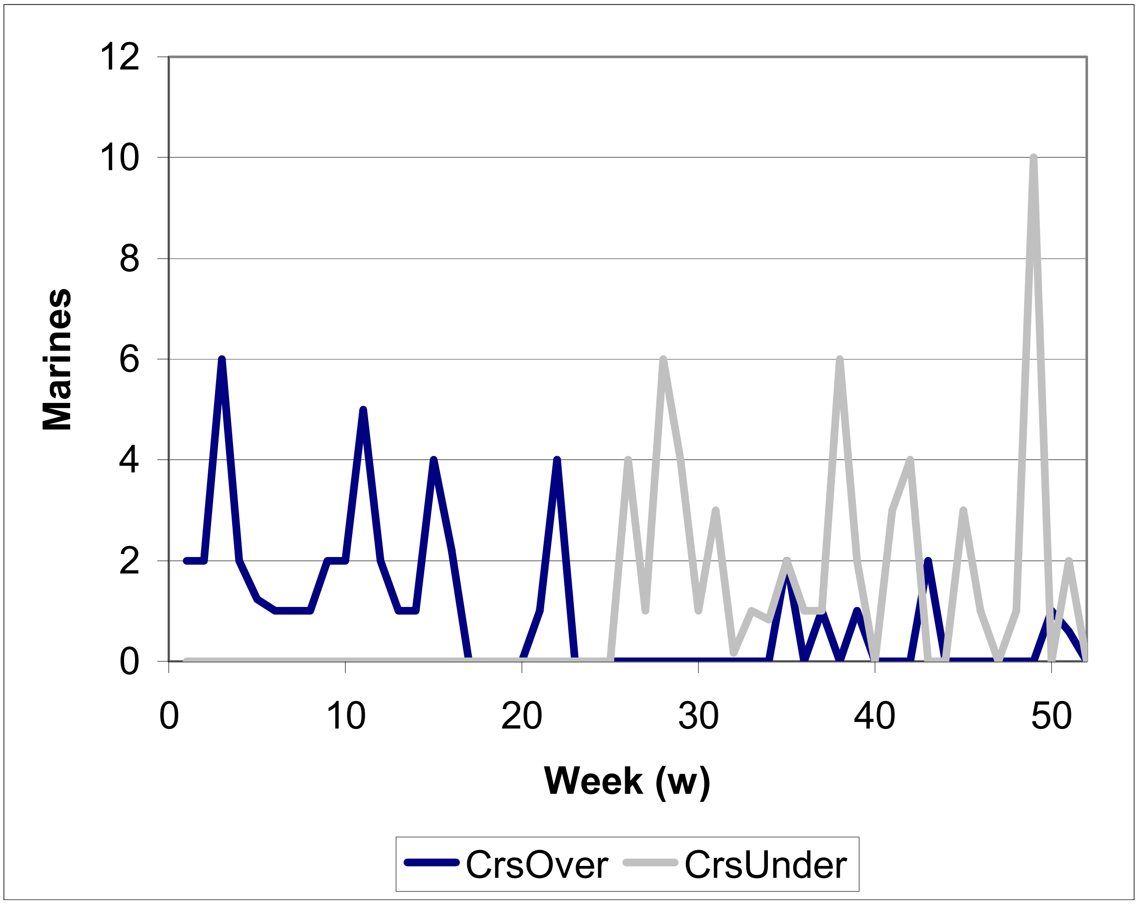

Figure 9. Weekly Total Course Size Violations
The graph depicts the total class size violations each week. Use this figure with Figure 8 to compare MCT graduation impact on violations. For example, in week 10 a total of 2 Marine exceed their class size and none fall below the minimum class size.

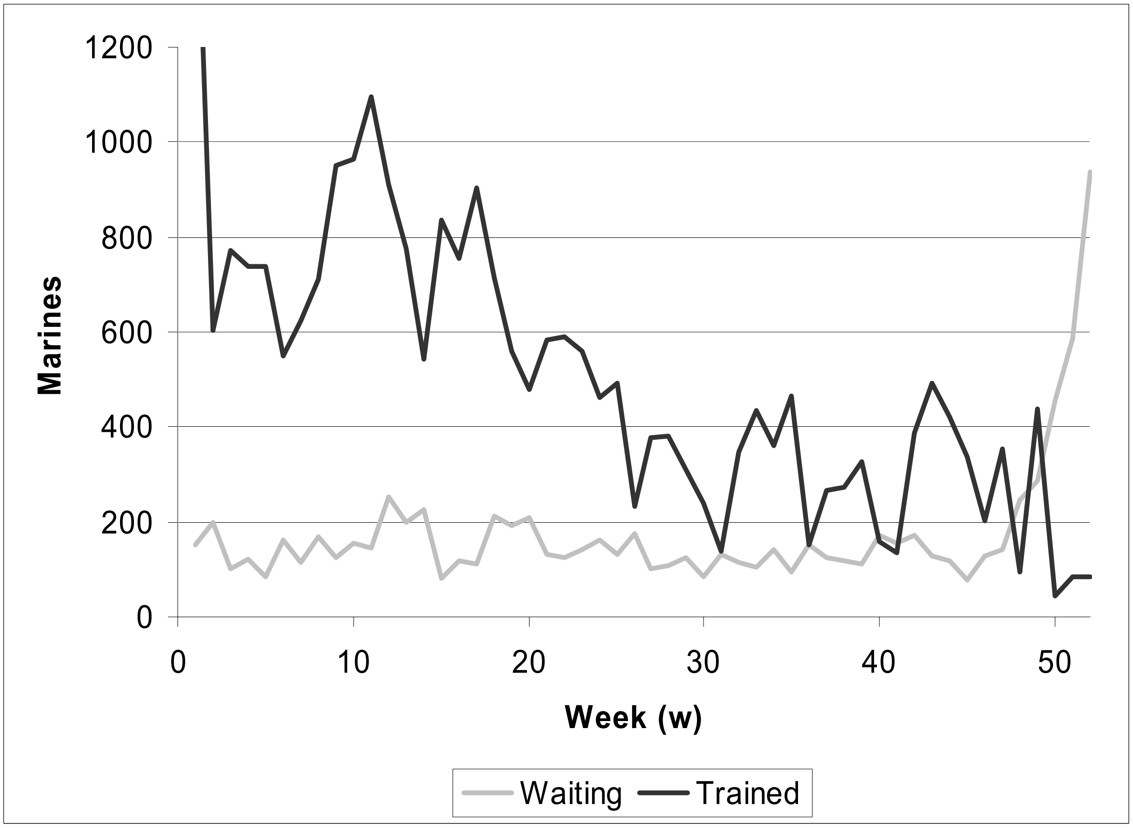

Figure 10. Weekly Comparison of $TRAIN_{gsw}$ and $WAIT_{gpw}$.

Figure 10 shows a weekly comparison of Marines waiting or beginning training. The increase in waiting and decrease in training Marines at the end of the year is because of the pUnderInitial value (Figure 8). By coincidence, the model manages to keep the number of waiting Marines fairly consistent throughout the year, which benefits the Marine Corps because these Marines can be used for recruiting or administrative jobs at the MOS schools.

Variable	Total	Units
Objective Function Value	18840	(Marine-weeks)
WAIT (Marine-weeks)	9108	(Marine-weeks)
TRAIN+OVERTRAIN	22624	(Marines)
recruit	22650	(Marines)
OVERINITIAL	3	(Marines)
UNDERINITIAL	483	(Marines)
COURSEUNDER	57	(Marines)
COURSEOVER	48	(Marines)
GROUPUNDER	48	(Marines)
GROUPOVER	90	(Marines)
MAXSTARTVIOL	0	
CMAXSTARTVIOL	0	
START	2201	
Maximum Possible Starts	2459	
CSTART	415	
Maximum Possible Cstarts	443	

Table 22. ELCS Results Summary
Results describe a run using the cascading (shown in Chapter V, Section D) with a 5% gap during each iteration and discounting (shown in Chapter IV, Section C).

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

During fiscal year 2001 (the most recent complete time-awaiting-training data), 2,500 man years were lost to time awaiting training of non-infantry recruits before completion of MOS training and reporting to their first unit. An estimated 1,200 man years of the loss occurs before Marine Combat Training (MCT) with the remaining 1,300 occurring between MCT and MOS attainment. Our results indicate a reduction in the post-MCT time awaiting training to 165 man years under ideal conditions. This would reduce the 2,500 total man-year losses to 1,365, an improvement of 45% over fiscal year 2001 data. Results also indicate increasing current course frequencies and size has no significant impact on reducing time awaiting training, when using an optimal master schedule. In fact, under ideal conditions, ELCS had no use for 258 of the 2,459 allowable course offerings in fiscal year 2003 (we determine course offerings by maximum frequency of initial MOS course except for MOSs sharing a common course, where we use the maximum frequency of the final course in their sequence).

B. RECOMMENDATIONS

We recommend the Marine Corps adopt the findings of this thesis and conduct all future MOS school scheduling using centralized planning and decentralized execution with all available planning documents. We recommend the Marine Corps use ELCS as the scheduling tool to help them realize the full savings available. We also strongly urge manpower planners to determine a by Marine request for information or survey to better collect data for future studies or for comparative analysis between the executed schedule and optimized schedule (i.e., shipment date, MCT graduation date, program, MOS assigned, MOS school commencement date, et cetera). In the event this information is already tracked, we recommend comparison of model results with fiscal year 2003 actual arrivals by program.

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